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RESEARCH MEMORANDUM

SUMMARY OF NORMAL ACCELERATIONS, GUST VELOCITIES, AND

OPERATING PRACTICES FROM APRIL TO AUGUST 1949

OF A TWIN-ENGINE AIRPLANE IN COMMERCIAL

TRANSPORT OPERATIONS

By Roy Steiner and Robert L. McDougal

Langley Aeronautical Laboratory
Langley Air Force Base, Va.

NATIONAL ADVISORY COMMITTEE
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SUMMARY OF NORMAL ACCELERATIONS, GUST VELOCITIES, AND OPERATING PRACTICES FROM APRIL TO AUGUST 1949 OF A TWIN-ENGINE AIRPLANE IN COMMERCIAL TRANSPORT OPERATIONS

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SUMMARY

The first sample of time-history data of airspeed, altitude, and normal accelerations obtained by means of the NACA VGH recorder in transport operations has been collected and is reported. The type of data obtained defines the distribution of normal accelerations and airspeeds experienced in greater detail than the maximum acceleration and airspeed data obtained by means of the NACA V-G recorder. Two hundred and eighty-one hours of the time-history data obtained from a modern twin-engine transport airplane are summarized. The frequency distribution of normal accelerations and of effective gust velocities are presented along with some data on the operating conditions and practices.

INTRODUCTION

The past work on gust loads experienced by commercial transport airplanes has dealt mainly with the large, but relatively infrequent, gust loads which may cause structural damage or failure under the application of a single load. The NACA V-G recorder has been well suited for the collection of this type of data in the form of envelopes of airspeed and normal acceleration. A need has existed, however, for a more detailed knowledge of the magnitude and frequency of gust loads in connection with certain operating and design problems, particularly in the study of the fatigue life of airplanes. Such detailed data must be obtained from a time-history type of instrument such as the NACA VGH recorder. Estimates of the frequency distributions of gust velocities experienced on transport airplanes were given in reference 1. In order to extend this work, a program has been initiated to collect airspeed, altitude, and acceleration data on commercial transport airplanes to determine the gust and load experience as related to operating practices.

The first sample of NACA VGH data consists of 281 hours of time-history records obtained on a modern, twin-engine, transport airplane in commercial operations. Although this sample is not sufficient for a comprehensive analysis of the factors mentioned, the data were considered to be of interest to the airplane industry. The data have been summarized, therefore, to give the frequency distributions of the normal accelerations and of the effective gust velocities encountered by this airplane with some indications of the operating conditions and practices.

APPARATUS AND OPERATING CONDITIONS

The airplane used in the present investigation was a modern, twin-engine, transport airplane with the following characteristics:

Design gross weight, lb	39,900
Wing area, sq ft	864
Span, ft	93.3
Mean aerodynamic chord, ft	10.1
Slope of lift curve, per radian (used in analysis)	5.00
Aspect ratio	10.1
Design level speed V_L, mph	255

The NACA VGH recorder was used in the present investigation. Whereas the NACA V-G recorder inscribes a flight envelope of airspeed and vertical acceleration, the NACA VGH recorder gives a time history of airspeed, altitude, and vertical acceleration. This instrument was used for the first time in the collection of the data contained in this paper. A brief description of the instrument is therefore given. Recording of the three functions is effected optically on photographic paper which is continuously driven at a speed of about 24 inches per hour. The instrument base and recording magazine together are $5\frac{3}{4}$ inches wide by $8\frac{1}{4}$ inches high by 12 inches long and weigh 17 pounds. Included in the base are the airspeed and altitude capsules, 1-minute timer, a galvanometer receiver for the acceleration signal, and the associated parts of the optical system. The record magazine contains a 200-foot roll of 70-millimeter recording paper along with the motor and driving transmission. A remote acceleration transmitter is mounted near the center of gravity of the airplane and is electrically connected to the instrument base. The base is installed in the radio rack with connections made to 24-volt d-c. power system and pitot-static lines of the airplane.

Continuous time-history records were taken during commercial transport operations between New York, N. Y. or Washington, D. C. and Seattle, Wash. during the period from April 1949 to August 1949 at altitudes less than 10,000 feet above terrain. The average pressure altitude was approximately 6,500 feet. The average duration of the flights was approximately 1 hour.

EVALUATION OF DATA AND RESULTS

The evaluation of the records was performed in the following manner: Each flight was first divided into the climb, enroute, and descent conditions. The climb condition began at the moment of take-off and was assumed to end when the record indicated that the airplane began maintaining a relatively constant altitude. Conversely, the descent condition was assumed to start when the record indicated that the airplane was consistently losing altitude and ended when the airplane landed. The enroute condition was taken as the time between climb and descent and necessarily contains changes in altitude for such reasons as the avoidance of turbulence or terrain clearance. Where applicable, each of these flight conditions was in turn subdivided into smooth and rough air. Rough air, as defined in the present paper, is represented by that portion of the record on which the accelerometer trace was disturbed and contained acceleration increments, Δn, equal to, or greater than $\pm 0.1g$. For each portion of the flight record, the following data were obtained:

(1) Flight time

(2) Total count of acceleration increments equal to or greater than $\pm 0.3g$

(3) Frequency distribution of acceleration increments above a threshold of $\pm 0.5g$

(4) Maximum acceleration increment

(5) Average indicated airspeed, V_i, miles per hour

(6) Altitude information

A summary of the data from the available flights was compiled and is given in tables I and II.

The proportion of flight path within given altitude brackets above terrain were obtained for flight in rough and smooth air. For this purpose, the altitude above terrain was based on the terminal altitudes; with no variations of terrain between terminals being considered. The altitudes for the climb condition were determined by subtracting the pressure altitude at the point of take-off from the pressure altitudes in climb. For the enroute condition, the average pressure altitude of the take-off and landing points was subtracted from the enroute pressure altitudes. For the descent condition, the pressure altitude of the terrain at the point of landing was subtracted from the descent pressure altitudes. A summary of the altitude data for 5000-foot intervals is also given in table I.

The frequency of occurrence of acceleration increments was determined to a threshold of ±0.3g, since smaller values were difficult to read for the present recording speed. The results obtained are summarized in figure 1 in the form of a plot of cumulative frequency against acceleration increment. The cumulative frequencies are obtained by the progressive summation of the frequencies of occurrence of values equal to or greater than a given acceleration increment and thus the curve shows at a glance the number of acceleration increments which equal or exceed the given value. Although the acceleration increments were read only to ±0.3g, it is believed feasible to extrapolate the frequency of occurrence to the smaller increments and, in fact, it is necessary to make such an extrapolation to determine the frequency for the threshold of turbulence as defined (0.1g). Based on some previous work, the extrapolation on a graph such as figure 1 can be made by fitting a straight line, by the method of least squares, through the data above 0.5g and then extending the line in the shape of a parabola to the lower values of acceleration increments. The fitted parabola satisfied the conditions that it passed through the point of 0.3g and was tangent to the fitted line at 0.5g. The extrapolation is shown in figure 1 as a dash line.

PRECISION

The airspeed and altitude data presented are average values. It is estimated that these average values are accurate to within ±3 miles per hour and ±500 feet for airspeed and altitude, respectively. Although the accelerometer is accurate to ±2 percent, the acceleration data may not represent the actual vertical acceleration of the airplane to within these limits because of the dynamic response of the airplane structure. Available test data indicate that for this airplane the accelerations measured at the center of gravity may be as much as 20 percent higher than the accelerations of the equivalent rigid airplane.

DISCUSSION

The summary of information presented in tables I and II indicates several items concerning the operating practices for the present operations and the rough-air experience. Perhaps, the most significant point is the large proportion of time (approx. 40 percent) spent in rough air. Previous work (reference 1) has suggested an average distance in rough air of about 10 percent of the flight path, but this figure was based on a somewhat different definition of rough air and the two values may not, therefore, be directly comparable. In order to permit comparison of the results of the present investigation with previous results (reference 1) in terms of path ratio based on a gust-frequency count, the acceleration and airspeed data were evaluated to obtain the frequency distribution of effective gust velocities.

The evaluation of the effective gust velocities U_e was accomplished on the basis of the sharp-edge gust equation for all values of Δn above 0.5g. The airplane weight used in the computations was an assumed average of 85 percent of the gross weight. The value of the alleviation factor K, which enters into the gust equation, associated with this weight was also used. For convenience and simplicity of evaluation, the airspeed used was the average airspeed in rough air in a given flight condition. The distribution of effective gust velocities obtained is shown in figure 2 as a cumulative-frequency distribution (as in fig. 1) with a curve faired through the data. For purposes of comparison, the cumulative-frequency distributions based on curves A and B of figure 7, reference 1, and an average path ratio of 0.1 were evaluated and are also shown in figure 2.

Examination of figure 2 suggests that the present data follow the shape of curve B over the range of most of the data. Furthermore, curve B of figure 2 and the present data both appear to describe the distribution of gust velocities obtained at low altitudes. It appears reasonable to assume, therefore, that the present gust experience can be represented by a distribution defined by curve B. On this assumption, a comparison of the frequency of occurrence for the present data and curve B for a given gust velocity indicate that, in general, the frequency of occurrence for the data is approximately one and one-half times the frequency of occurrence for curve B. For example, at a gust velocity of 12 feet per second, the present data and curve B indicate frequencies of occurrence of 110 and 80, respectively, or ratio of approximately 1.4. Above a gust velocity of 15 feet per second, such a comparison is considered invalid due to the small number of observations. Inasmuch as curve B was based on a path ratio of 0.10 as determined from previously published data, the data presented herein would, therefore, be indicative of a path ratio of about 0.15 based on the frequency count of gust velocities.

The high proportion of time spent in rough air probably results from the low-altitude level of the present operations. As indicated in table I, about 65 percent of the flight distance was spent below 5000 feet above the average terminal altitudes with 44 percent of this distance in rough air. The low altitudes of the present operations apparently occur because of the very short flights made, averaging about 1 hour, and the relatively large proportion of time, about 32 percent spent in descent.

Returning to the discussion of general points of interest, table I shows a reduction of 10 to 15 miles per hour in airspeeds for flight in rough air as compared to the airspeeds for flight in smooth air in similar flight conditions. This constant difference in the airspeeds in rough and smooth air indicates a consistent effort to reduce airspeed in rough air. The records further indicate that more drastic speed reductions were frequently made when severe turbulence was encountered.

The average values of airspeed in the descent are lower than those in the enroute conditions although in the past it was indicated, for other airplane types, that there was a tendency to obtain excessive airspeeds in the descent condition. This deviation from previous experience may be due to inherent airplane characteristics or the special restrictive operating instructions and practices under which this airplane was operated at the time.

As a final point, the variations in the load experience among individual records are of interest. Table II indicates variations of about 2 to 1 in the portion of flight in rough air for the five records and variations of about 4 to 1 in the number of acceleration increments, equal to or greater than $\pm 0.3g$, per mile of flight in rough air. These preliminary results serve to indicate the type of variations in load experience that might be expected within a given set of operations.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Air Force Base, Va.

REFERENCE

1. Rhode, Richard V., and Donely, Philip: Frequency of Occurrence of Atmospheric Gusts and of Related Loads on Airplane Structures. NACA ARR L4I21, 1944.

TABLE I

SUMMARY OF NACA VGH DATA FOR A TWIN-ENGINE AIRPLANE IN COMMERCIAL

TRANSPORT OPERATIONS FROM APRIL TO AUGUST 1949

(a) Operating conditions

Flight condition	Flight time, (hr)			Percent time in flight condition	Portion of flight path at altitude above terrain					
					0-5,000 feet		5,000-10,000 feet		Above 10,000 feet	
	Rough air	Smooth air	Total		Rough	Smooth	Rough	Smooth	Rough	Smooth
Climb	11.90	15.31	27.21	9.67	0.032	0.037	0.003	0.008	0.000	0.000
Enroute	48.39	115.02	163.42	58.07	.106	.218	.067	.211	.001	.001
Descent	51.74	39.03	90.77	32.26	.153	.117	.020	.026	.000	.000
Total	112.03	169.36	281.4	-----	.291	.372	.090	.245	.001	.001

(b) Airspeed and Normal-Acceleration Data

Flight condition	Flight time (hr)	Average indicated airspeed (mph)		Portion of flight condition in rough air	Number of $\Delta n_g \geq \pm 0.3g$	Number of $\Delta n_g \geq \pm 0.3g$ per mile of rough air	Maximum Δn (g units)
		Rough	Smooth				
Climb	27.21	165.8	163.9	0.44	722	0.366	0.70
Enroute	163.42	200.6	210.7	.28	3322	.342	1.10
Descent	90.77	188.6	206.1	.55	3982	.408	.85
Total	281.4	-----	-----	----	8026	-----	----
Average	-----	-----	-----	.38	----	.374	----

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TABLE II

COMPARISON OF GUST-LOADS DATA FROM FIVE NACA VGH RECORDS

Record	Total number of flight hours	Number of $\Delta n_s \geq \pm 0.3g$	Maximum $\pm \Delta n$	Portion of flight in rough air	Number of $\Delta n_s \geq \pm 0.3g$ per mile of rough air
1	65.22	3004	1.10	0.40	0.59
2	63.56	2551	−.92	.48	.42
3	34.85	625	.92	.41	.22
4	65.91	544	−.71	.27	.15
5	51.86	1296	−.78	.36	.35
Total	281.40	8026	----	----	-----
Average	------	----	----	.38	.374

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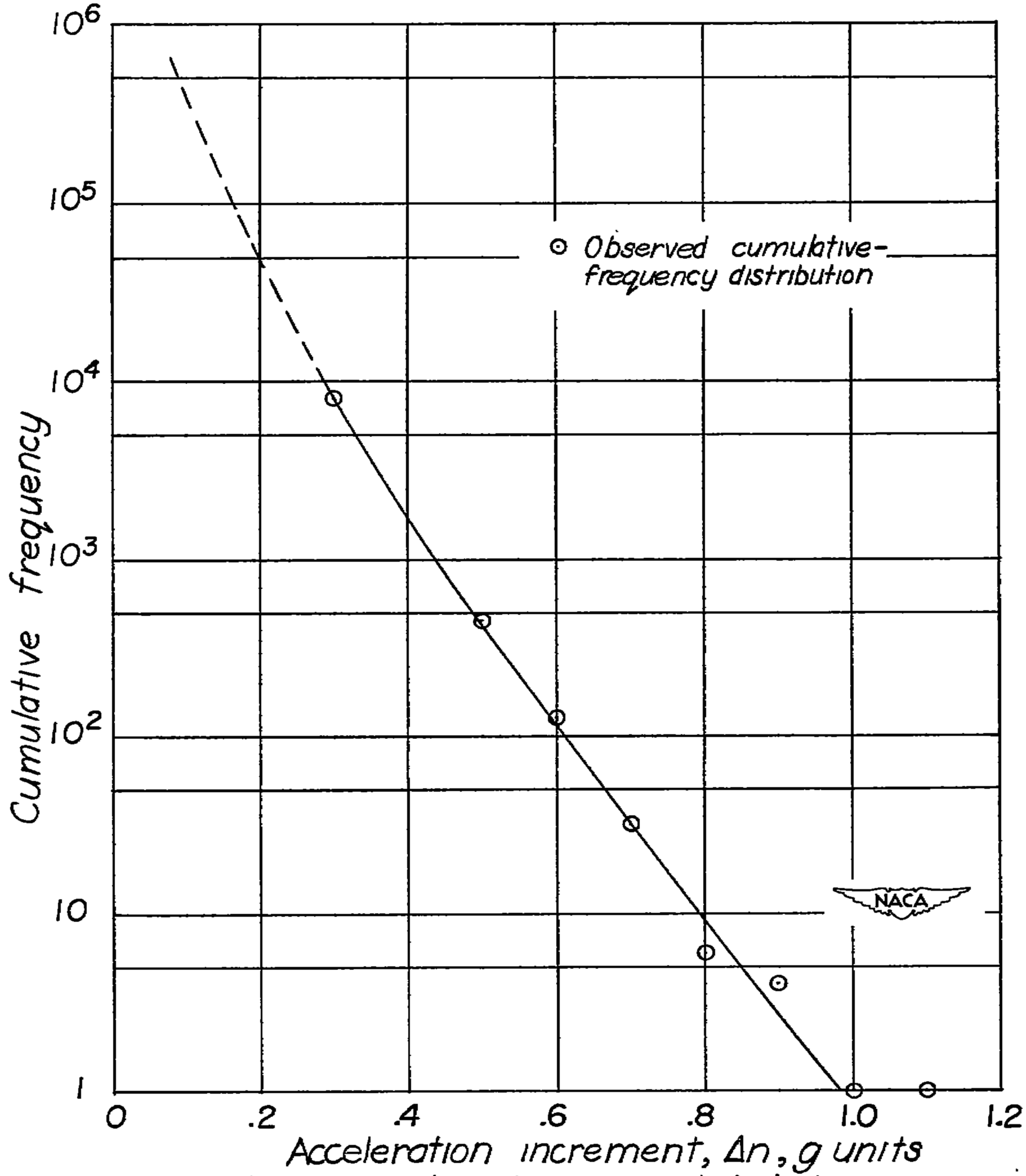

Figure 1.- Cumulative-frequency distribution of acceleration increments.

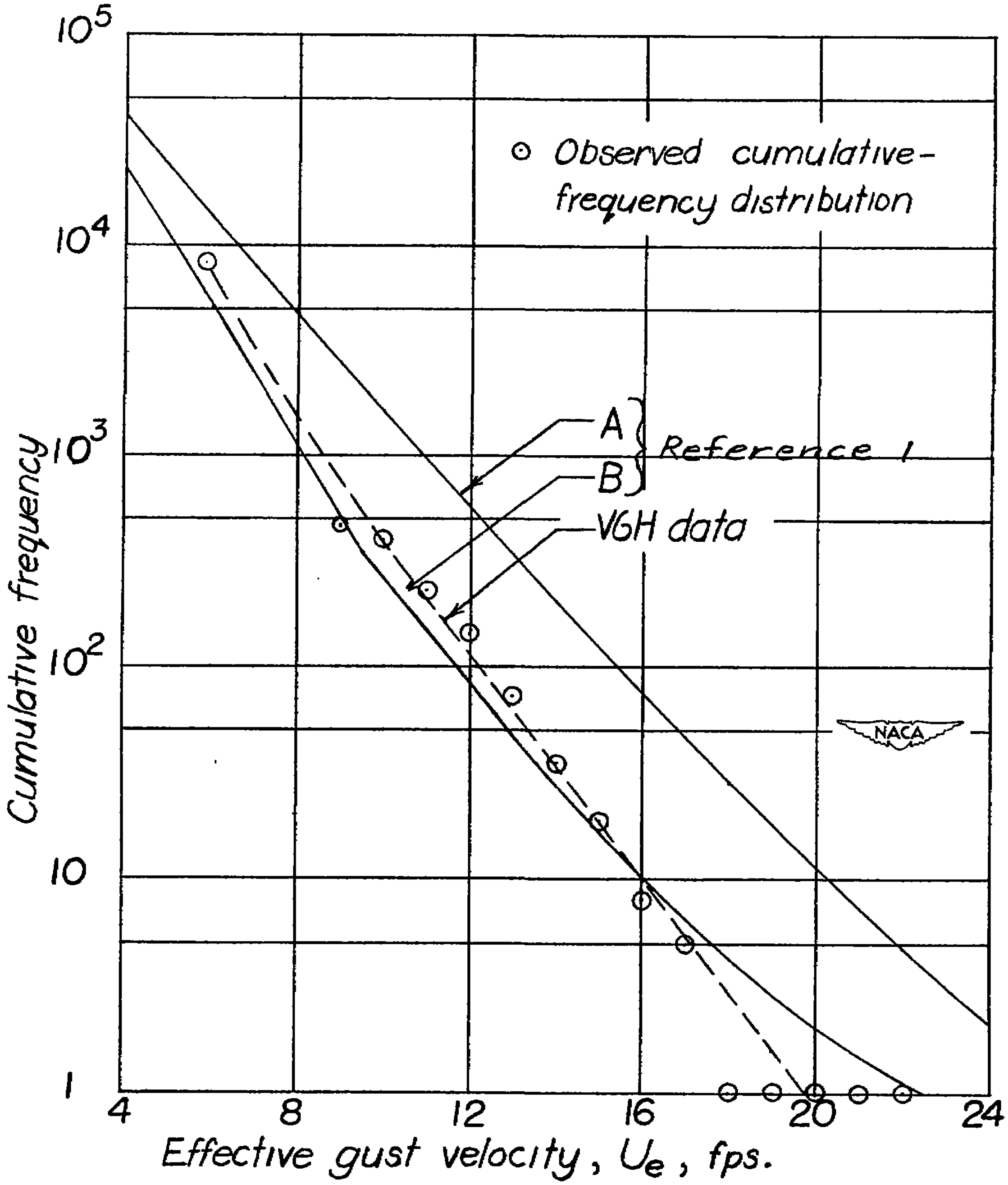

Figure 2.- Cumulative-frequency distribution of effective gust velocity.